LIGHTNING SHIELDING OF PLASTIC TELEPHONE CABLE

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ABSTRACT

Data is presented on the surge characteristics of various types and combinations of metals when applied as a shield for buried telephone cables. Surge currents were applied to the shield of 500 foot lengths of cable and the potentials developed between the shield and conductors were measured at selected points along the cable length in order to determine relative susceptibility to lightning influence. The shield metals included copper, aluminum, stainless steel and low carbon steel, and combinations of these metals. This program was begun and completed in the calendar year 1968. This program may have a substantial impact in the future designs of cable used in the REA systems.

INTRODUCTION

The susceptibility of wire connecting facilities in telephone systems to damage by lightning strokes has been a continuing problem to protection engineers ever since the inception of telephone communication.

At first, the connecting conductors were the familiar "open wire." These had to be widely separated and of heavy gauge for mechanical reasons and were therefore inherently capable of withstanding lightning strokes without excessive damage. In open wire systems, the primary lightning problems concerned the protection of the subscriber's station and central office facilities.

With the advent of cable as a connecting facility, additional problems arose. For many years, telephone cable was constructed using paper or pulp insulated conductors, usually carried in a lead sheath. The dielectric strength of the conductor insulation was only about 1500 volts and consequently this cable was extremely susceptible to breakdown from conductors to sheath or from conductor to conductor. Except where cable was entirely underground in highly shielded areas, extensive use of low breakdown arrestors between the conductors and shield was required. These costly protective measures were especially needed since the breakdown of paper insulation, even by short duration surges, resulted in a carbonized, highly conductive path and an interruption in service.

With the development of cable using polyethylene insulated conductors, the protection problem was relieved to a major degree because: (1) the dielectric strength of the cable was increased at least tenfold; and (2) the discharge of lightning surges through the plastic insulation resulted in a clean path (not carbonized) and a less troublesome leakage condition. As a result REA protection practices have been revised to provide only for limited application of inexpensive air gap arrestors (washer gaps). It is notable that only under the most severe exposure conditions does REA experience lightning breakdown between conductor and shield of its (unprotected) aerial cable, which carries no inner insulating sheath.

Figure 1 shows a typical cable structure for direct burial wherein the core is covered with a polyethylene jacket, a corrugated metal shield and an outer polyethylene jacket.

REA protection practices have been developed on the basis that the structure of the cable would use 5 or 10 mil copper or 8 mil aluminum shield and polyethylene insulated conductors. The periodic shortage and high cost of copper has prompted consideration of substitute shield materials such as bronze, low carbon steel, aluminum, and combinations of copper and aluminum with stainless and low carbon steels.

TEST PROCEDURE

For many years protection engineers have considered conductor to shield potentials, developed by lightning currents in the shield, to be a function of shield resistance, regardless of the shield metals employed. In order to verify this assumption, tests were undertaken at the Bureau of Standards, High Voltage Section, in Washington.

These tests were conducted on samples of six pair 19 gauge cables, 500 feet in length strung in long loops in such a way as to minimize shield inductance. All of the cable conductors were connected to the shield at one end and left floating for the length of the cable. Surge currents ranging from 400 to 1800 amperes were applied using a 170 mf generator. Wave shape was kept constant by varying a small resistor in series with the shield. The test circuit is shown in Figure 2. Figure 3 shows a typical current wave.

Potential of the shield to ground and of one conductor to ground were measured by a cathode ray oscilloscope element at (1) the input point, (2) 170 feet and (3) 340 feet using the same voltage divider for both measurements. The difference between these measurements represents the conductor to shield potential. Figure 4 shows typical shield to ground and conductor to ground potential waves.

The following cable structures were tested. The order in which the letter designations appear corresponds with the order in which the elements of the cable structure appear starting at the cable core. All cables were six pair 19 gauge.

Cable Designation	Metals in Shield
Group A. Cables with Non-Magnetic Shields	
P - C - P	5 mil Copper
P - C - P	10 mil Copper
P - A - P	8 mil Aluminum
A - P - A - P	8 mil Aluminum + 8 mil Aluminum
A - F - SS - P	8 mil Aluminum + 5 mil Stainless Steel (304)
P - B - P	5 mil Commercial Bronze
P - C SSC - P	6 mil Copper Clad Stainless Steel (430) (2 + 2 + 2)
P - A SS - P	8 mil Aluminum + 3 mil Stainless Steel (211) Adhesively Bonded
P - Cu alloy - P	5 mil Copper alloy 194
Group B. Cables Using Aluminum and 6 mil Low Carbon Steel	
(Three samples) A - P - S - P	8 mil Aluminum + 6 mil 1011 Steel
P - AS - P	8 mil Aluminum + 6 mil 1011 Steel
Group C. Using Aluminum and 10 mil Low Carbon Steel	
A - P - S - P	8 mil Al + 10 mil 1011 Steel

RESULTS

The oscillographic data was analyzed to determine the relationship between shield current and conductor to shield potential. Measurements of conductor to shield potential were made at three points on each oscillogram, i.e., at the voltage peak, at the 100 microsecond point, and at the 150 microsecond point. These measurements were made at three positions along the test cable for four values of shield current at each position. From these measurements and the values of peak shield current an average value of conductor to shield volts per shield current ampere was obtained for each of the three test points.

Table 1 summarizes the results of these measurements. Values of conductor to shield potential for unit shield current are given for each of the three test positions.

From a cursory examination of this Table it is apparent that cables containing steel (other than non-magnetic stainless types) develop lower potentials per unit shield current than do those employing non-magnetic materials. Figure 5 illustrates more clearly the beneficial effect contributed by the presence of steel. In this graph the data from Table 1 has been plotted on a basis of <u>equal</u> <u>shield</u> <u>resistivity</u> in order to compare the effect of variations in shield materials (only), on the development of conductor to shield potentials. For these curves the data in Table 1 has been modified to reflect equal resistivity in all samples at 1 ohm per kilofoot, thus providing a direct comparison of the effect of materials. When so modified the data represented by each of the three curves was found to lie within $\pm$ 2% of the mean values.

Curve A represents the rate of increase of conductor to shield potential per unit shield current with increase in cable length for all of the cables using nonmagnetic shield materials. All of the nonmagnetic materials developed potentials to the conductors in direct proportion to shield current and shield resistivity.

Curve B shows comparable results obtained on the four samples of Group B incorporating a combination of 8 mils of aluminum and 6 mils of steel. The presence of the steel resulted in a 22% reduction in conductor to shield potential for the same shield currents and resistivity as in the cables covered by Curve A.

Curve C shows the performance of a cable constructed with a composite shield having 8 mils of aluminum and 10 mils of steel. Here the 10-mil steel component provided a 45% reduction in susceptibility in comparison with the nonmagnetic metals.

It is interesting to note that the cable designated P-CSSC-P, having only 2 mils of a magnetic type of stainless steel (430), showed a 7% decrease in conductor to shield voltage compared to the nonmagnetic metals.

Also, it was found that exactly the same results were obtained in the cables in which the aluminum and steel were separated by a jacket (A-P-S-P) as in the cable having the aluminum and steel components in contact throughout the length of the sample.

CONCLUSIONS

It is concluded that any nonmagnetic metal may be substituted for copper as a cable shield with equal expectation of conductor to shield potential for comparable shield resistivity.

Curves B and C show that the inclusion of a magnetic material in the shield structure, such as low carbon steel, results in a definite reduction in conductor to shield potential for a given shield resistivity. An increase in thickness of the steel results in proportionately greater voltage reduction, again on a basis of equal shield resistivity. This suggests that, by including a magnetic component in the shield structure, cable could be constructed with reduced core to shield insulation or the overall shield resistivity could be increased without degrading the lightning susceptibility of the conventional design.

Design Implications

Figure 6 illustrates two speculative designs taking advantage of the use of steel.

Figure 6a assumes that the moisture sealing effect contributed by the inner sheath is replaced by a member providing a positive seal without emphasis on dielectric qualities. If it is concluded that lightning is a serious offender in producing breakdown of the outer jacket, a semiconducting jacket could be substituted for the conventional insulating material.

Figure [illegible] makes the same assumptions as in 6a except that it is assumed that the outer shield component, possibly a magnetic type stainless steel, would be acceptable from a corrosion standpoint. Also, this design would require the shield to be formed in such a manner that it would maintain its integrity both during and after placement.

Additional factors which must be evaluated in any consideration of modified designs are (1) assurance that a positive hermetic seal with the shield can be achieved and retained and (2) noise susceptibility. The degree of reliability placed in the hermetic seal will depend much upon the results of the corrosion tests which are now being conducted in conjunction with the National Bureau of Standards. It is also intended to have these constructions tested for noise susceptibility, but at this point technical difficulties have limited testing.

REA's ultimate shield and cable design will depend to a great extent on the factors discussed above.

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TABLE I

Conductor to Shield Volts Per Ampere

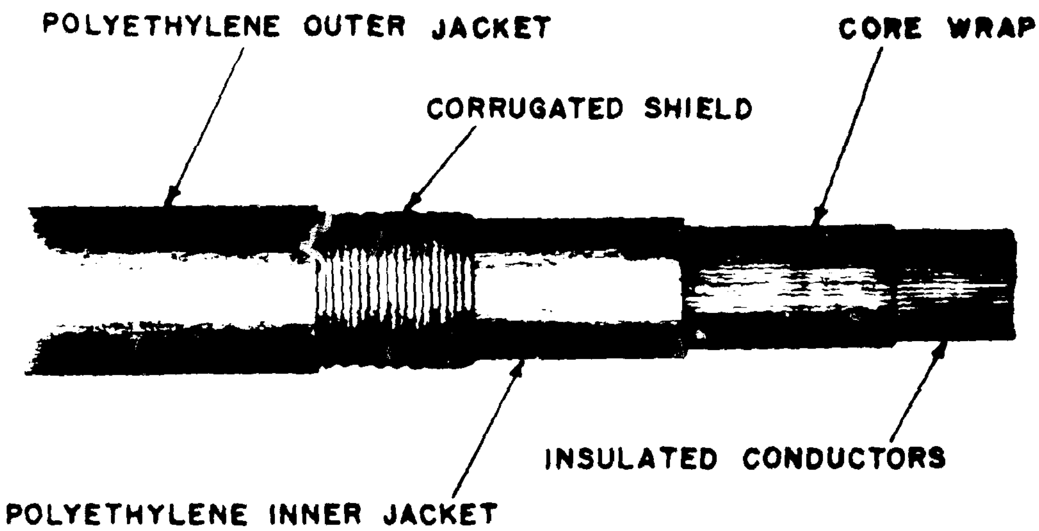
Averages for Four Current Values at Three Points

(a) Peak (b) 100 Microseconds (c) 150 Microseconds

	Pos. A (Input)	Pos. B (170')	Pos. C (340')	Shield Res. Ohms/1000'
5 mil PCP	.438	.281	.144	1.13
10 mil PCP	.203	.130	.069	.53
8 mil PAP	.450	.281	.145	1.20
8 + 8 mil APAP	.241	.152	.070	.62
8 + 5 mil APSSP	.591	.410	.211	1.51
5 mil P Bronze P	.844	.570	.275	2.22
6 mil PCSSCP	.475	.314	.152	1.35
8 + 3 mil PASSP	.435	.286	.138	1.16
5 mil PC alloy P	.491	.320	.157	1.31
8 + 6 mil APSP (1)	.368	.265	.130	1.24
8 + 6 mil APSP (2)	.292	.184	.091	.96
8 + 6 mil APSP (3)	.344	.236	.118	1.24
8 + 6 mil PASP	.260	.190	.099	.90
8 + 10 mil APSP	.180	.136	.060	.87

Fig. 1

TYPICAL DIRECT BURIAL CABLE



TEST METHOD FOR DETERMINING
CABLE CONDUCTOR TO SHIELD POTENTIALS
DERIVED FROM SHIELD SURGE CURRENTS

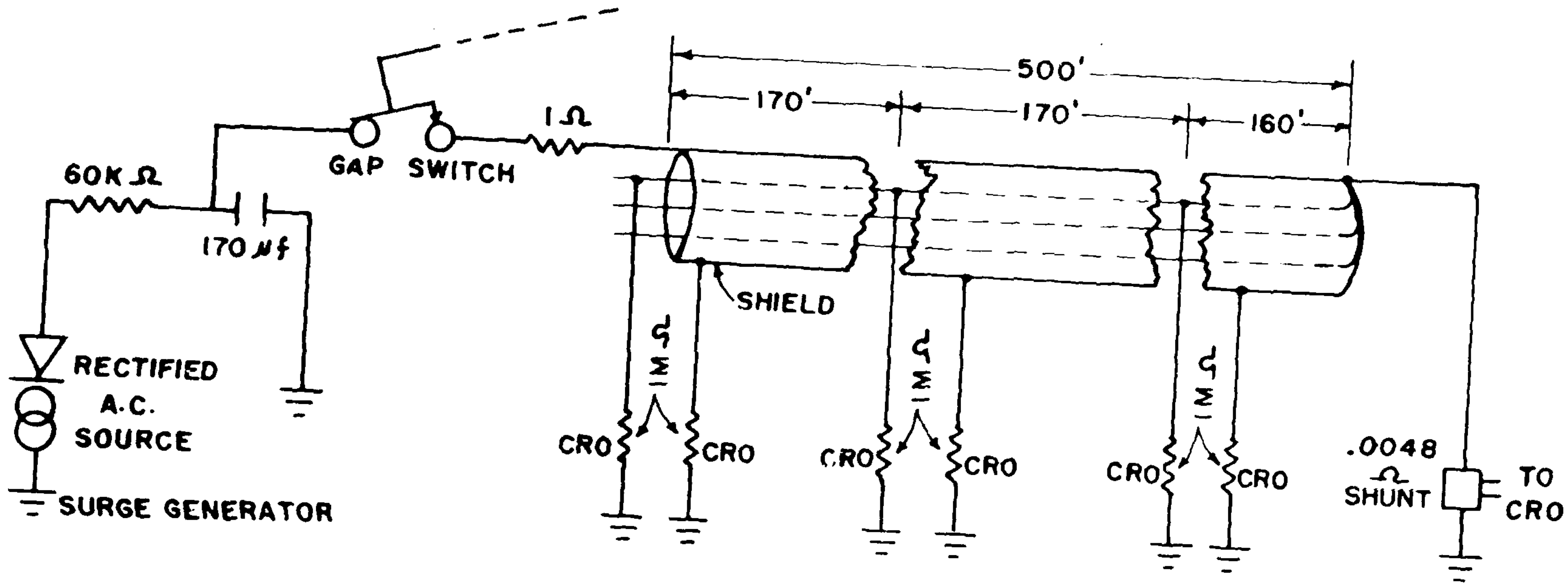


Fig. 2

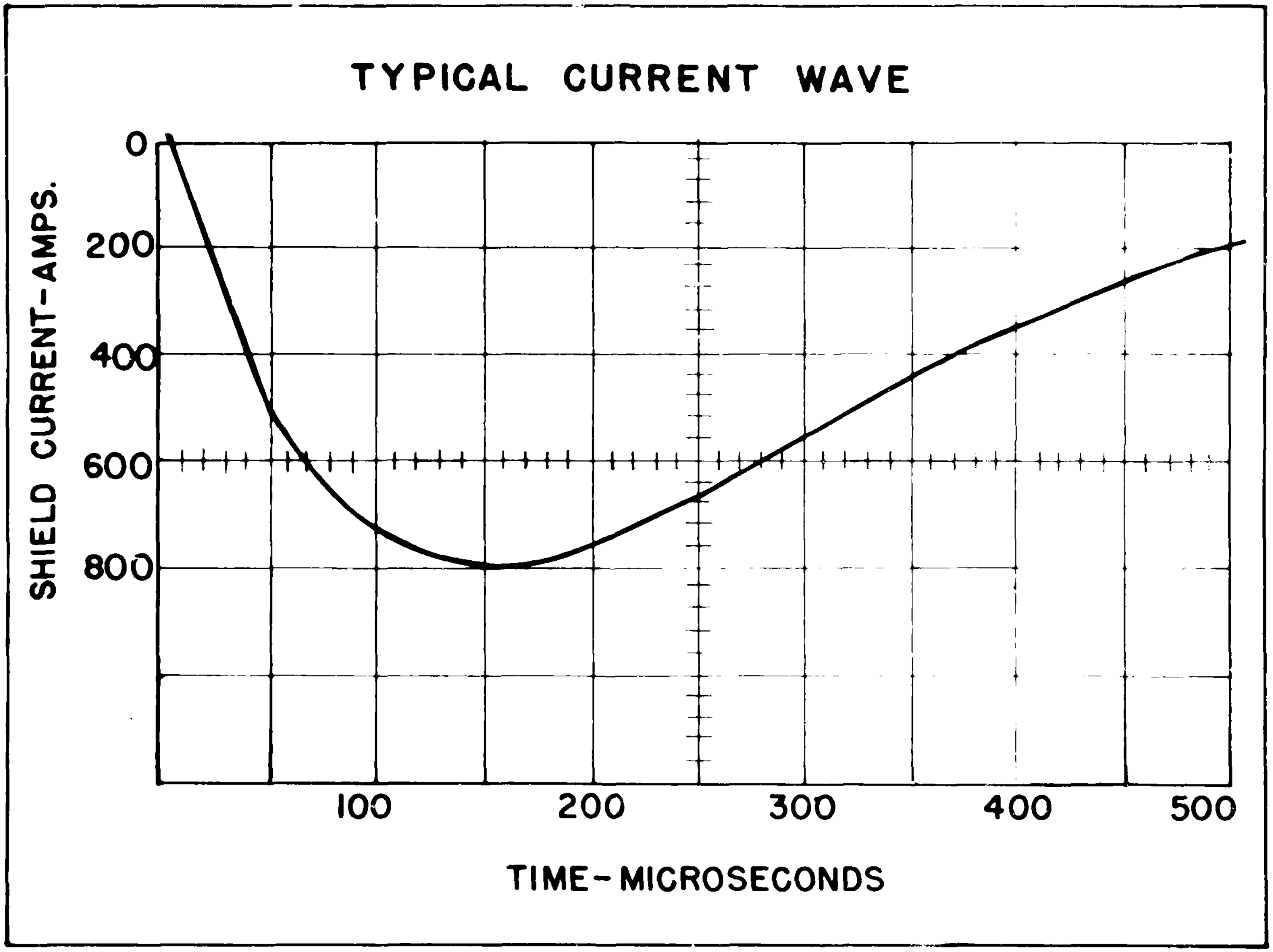

TYPICAL CURRENT WAVE
SHIELD CURRENT-AMPS.
0
200
400
600
800
100
200
300
400
500
TIME-MICROSECONDS

Fig. 3

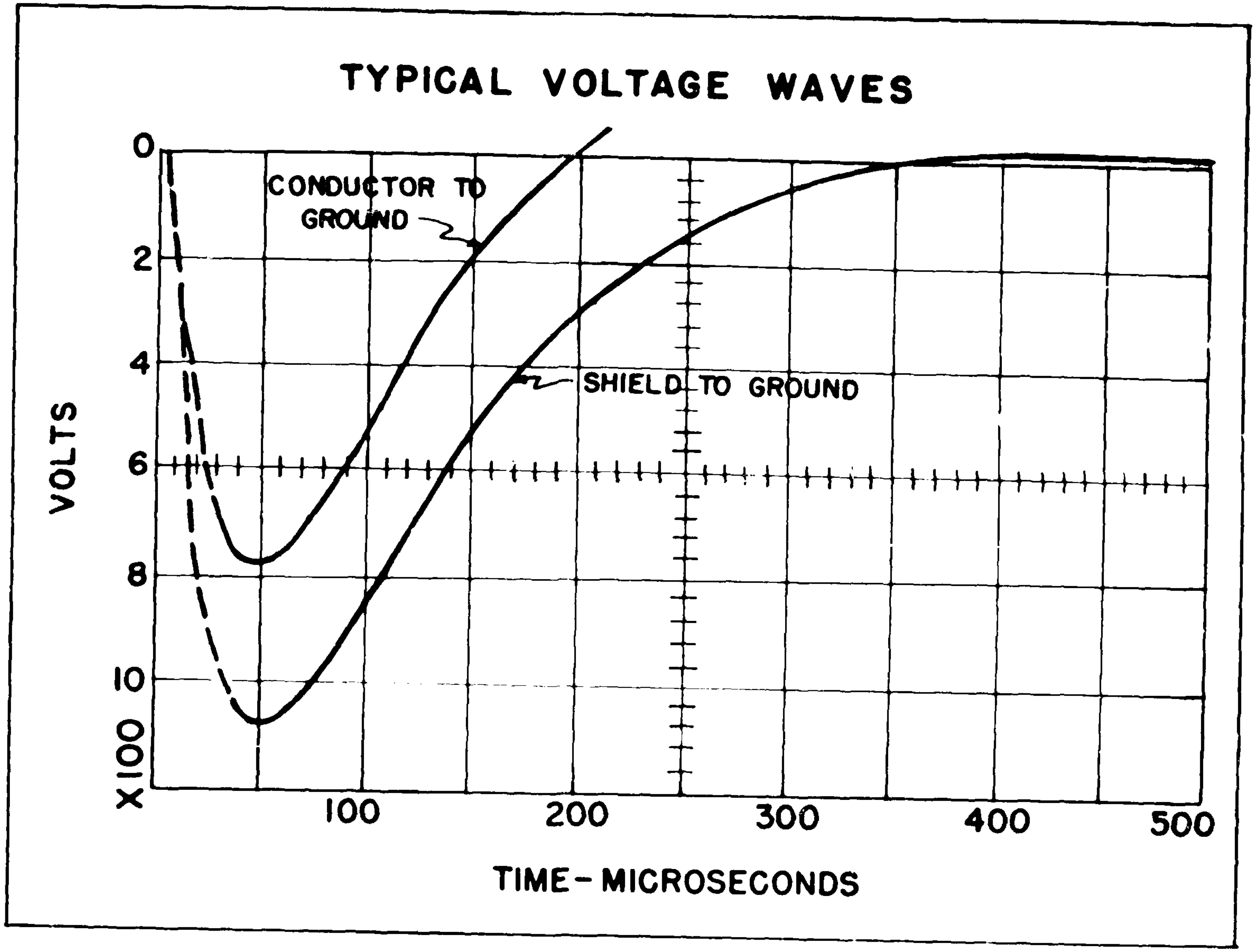
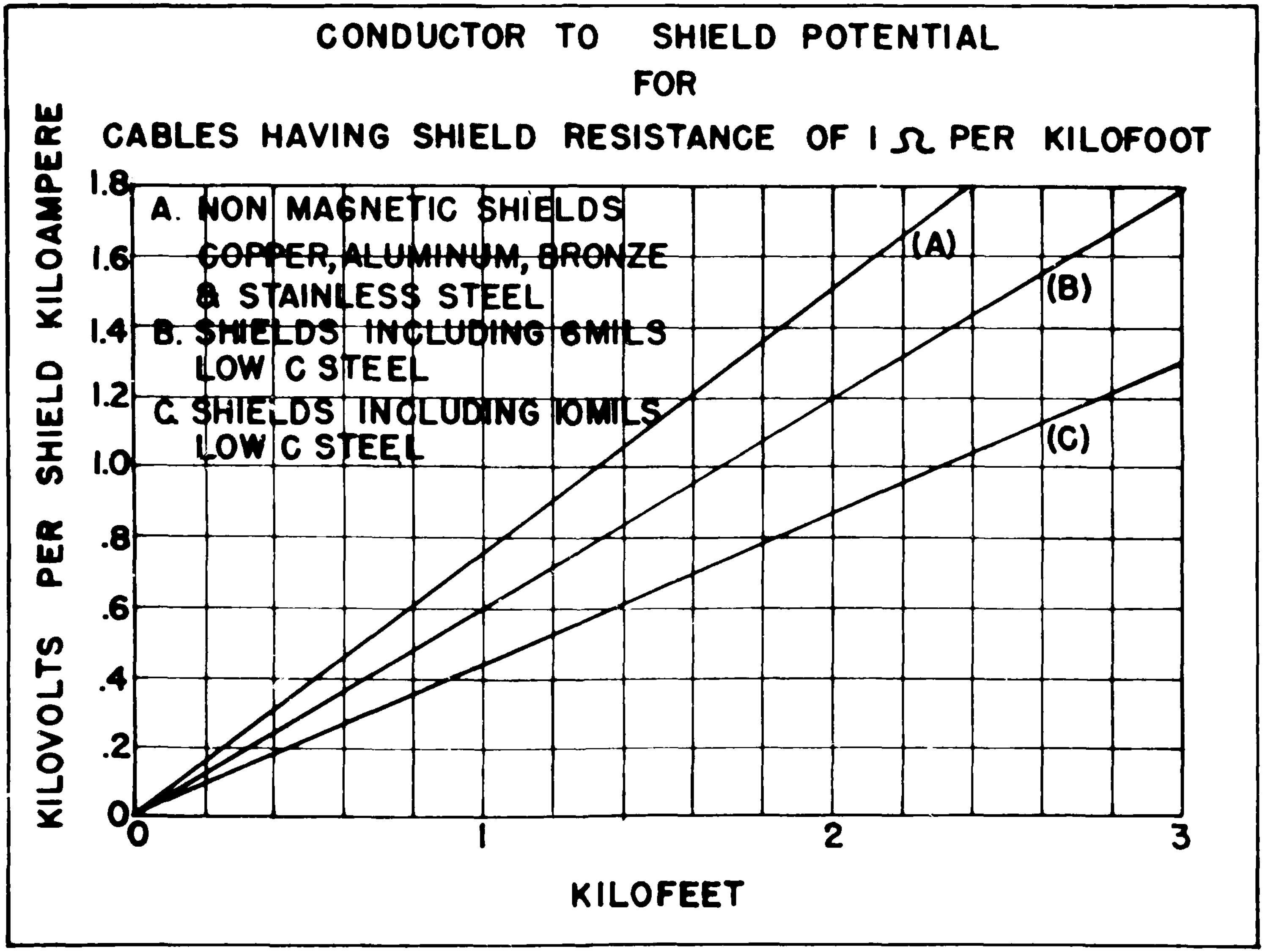

TYPICAL VOLTAGE WAVES
CONDUCTOR TO GROUND
SHIELD TO GROUND
VOLTS
X100
0
2
4
6
8
10
100
200
300
400
500
TIME-MICROSECONDS

Fig. 4



CONDUCTOR TO SHIELD POTENTIAL
FOR
CABLES HAVING SHIELD RESISTANCE OF 1 Ω PER KILOFOOT
A. NON MAGNETIC SHIELDS
COPPER, ALUMINUM, BRONZE
& STAINLESS STEEL
B. SHIELDS INCLUDING 6MILS
LOW C STEEL
C. SHIELDS INCLUDING 10MILS
LOW C STEEL
(A)
(B)
(C)
KILOVOLTS PER SHIELD KILOAMPERE
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
0
1
2
3
KILOFEET

Fig.5

Fig. 6

SPECULATIVE LIGHTNING RESISTANT CABLE CONSTRUCTIONS